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Some more results on 0°C isotherm height over several Indian stations for rain attenuation estimation

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Abstract : The results on 0°C isotherm height over Trivandrum, Mumbai, Guwahati and Lucknow are presented in this paper It is seen that 0°C isotherm height is maximum during monsoon months and minimum during winter season The variation of 0°C isotherm height has also been discussed in relation to local weather characteristics On the basis of rain height in relation to 0°C and rain rate measurements, the results on attenuation of radiowave due to rain at five different frequencies lying in the range between 10 GHz and 400 GHz for earth space path over Calcutta have been derived and also presented in this paper

Keywords : 0°C isotherm height, rain attenuation, weather characteristics

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1. Introduction

Rain height is one of the important parameters needed for estimation of attenuation of radiowave in satellite communication and radar propagation. There is dearth of data on rain height over the Indian stations. However, some results on rain height were reported recently by Sarkar *et al* [1], over Bangalore, Calcutta and Delhi. It is well known at present that rain height can be taken as 0°C isotherm height [2–4]. Such results can be obtained from the upper air measurements. The upper air observations are taken twice a day, one at 0000 GMT and the other at 1200 GMT, corresponding to early morning and late evening local time

The results on 0°C isotherm height over some more stations, namely, Trivandrum, Mumbai, Guwahati and Lucknow for different seasons are presented in this paper.

Trivandrum (8.29°, 76.57°) and Mumbai (19.07°, 72.51°) are coastal stations located in south west coast and west coast of India having station elevation ~64 m and ~14 m respectively. Guwahati (26.11°, 91.45°) is located in north east region of India and having station elevation ~54 m, while Lucknow (28.52°, 88.20°) is situated in northern plains with an altitude ~128 m.

It is seen that the 0°C isotherm height in all months varies from 2.49 km to 5.98 km over these stations. The variation in 0°C isotherm height in different stations during winter is appreciable. The 0°C isotherm height varies between ~2.75 km and 5.82 km over these stations during summer months. Based on rain height in relation to 0°C isotherm height and measured rain rate over Calcutta, attenuation of the radio wave due to rain at five different frequencies lying in the range 10 GHz to 400 GHz has been obtained and presented in this paper. The distributions of 0°C isotherm height over different stations have been discussed in light of prevailing weather characteristics over the stations. The details of the weather characteristics are presented in Table 1.

Table 1. Weather characteristics over Trivandrum (TRVN), Mumbai (BMB), Guwahari (G and Lucknow (LKN)

	TRVN			BOM			GHT			LKN		
	Temp °C	Humidity %	Rain fall mm	Temp °C	Humidity %	Rain fall mm	Temp °C	Humidity %	Rain fall mm	Temp °C	Humidity %	Rain fall mm
Jan	25	77	20	20	63	1	16	86	17	12	84	32
	29	63		27	48		18	74		19	58	
Feb	25	79	20	21	61	9	18	73	9	15	66	10
	29	63		28	45		22	58		24	39	
Mar	27	80	43	25	65	1	23	66	73	22	52	14
	30	66		30	50		26	53		30	29	
Arp	28	81	122	28	67	4	26	68	136	28	33	1
	29	73		31	57		•29	57		36	18	
May	27	84	248	30	69	20	27	79	276	32	37	14
	29	77		31	65		29	72		39	20	
June	26	90	331	28	80	647	28	84	351	32	59	71
	27	82		30	74		29	80		37	41	
July	25	89	215	27	86	945	28	85	373	29	83	338
	27	81		28	82		29	81		31	74	
Aug	25	88	164	26	87	660	29	85	294	29	86	329
	27	78		27	82		29	82		30	80	
Sep	26	86	123	26	86	309	28	83	190	28	81	158
	27	77		28	75		28	84		30	72	
Oct	26	87	271	27	75	117	26	83	86	25	71	57
	27	80		30	65		26	85		28	60	
Nov	26	87	207	25	61	7	22	83	8	18	65	8
	27	78		29	53		22	85		23	52	
Dec	25	80	73	22	62	.9	17	86	7	12	80	2
	28	69		28	50		19	83		19	59	

In temperature and humidity columns · upper values pertain to 0000 GMT and lower values pertain to 1200 GMT

2. Distribution of 0°C isotherm height in relation to local weather characteristics

The probability distributions of 0°C isotherm height for summer, monsoon, post monsoon and all months over Trivandrum are illustrated in Figure 1. It is found that the 0°C isotherm height during all months varies from ~3.25 km to 5.90 km. The 0°C isotherm height is ~4.80 km at 50% probability level over Trivandrum. Actually, it means that 50% of the time ordinate value *i.e.* 0°C isotherm height (4.80 km) is exceeded

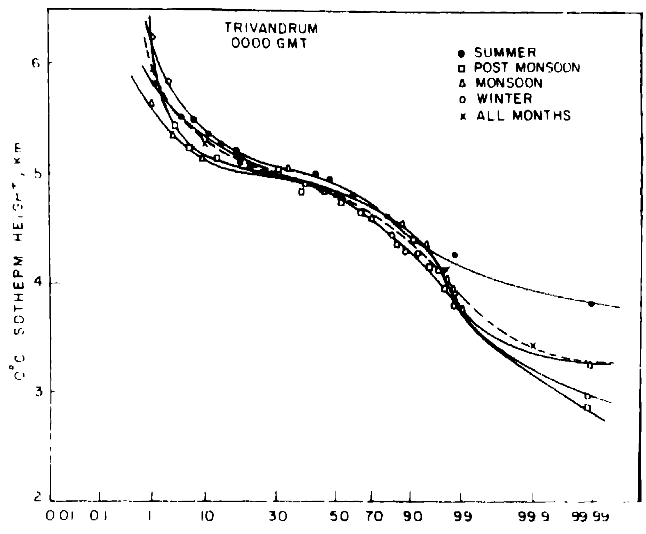

Figure 1. Probability distribution of 0°C isotherm height during different seasons over Trivandrum

The 0°C isotherm heights during monsoon months are found to vary between ~3.25 km and 5.65 km, while they vary between ~2.85 km and 6.25 km from 1% and 99% probability levels during non-monsoon months. The results on 0°C isotherm height reported here are useful to estimate the total attenuation over earth space path in frequencies varying from ~10 GHz to 100 GHz provided the distributions of rain rate over Trivandrum are also known

The weather characteristics over Trivandrum indicate that there is not much variation of ground temperature during all months in Trivandrum. The months of December, January and February in a year, constitute winter period. The average temperatures in Trivandrum in December, January and February are ~25°C, 25°C and 25°C at 0000 GMT and ~28°C, 29°C and 29°C at 1200 GMT respectively. The relative humidity is quite high (77%–90%) in Trivandrum. The average temperature in April and May are ~28°C and 27°C at both 0000 GMT and 1200 GMT respectively. The peak monsoon months are May, June, July, october and November in Trivandrum and the total rain fall during these months are ~248 mm, 331 mm, 215 mm, 271 mm and 207 mm

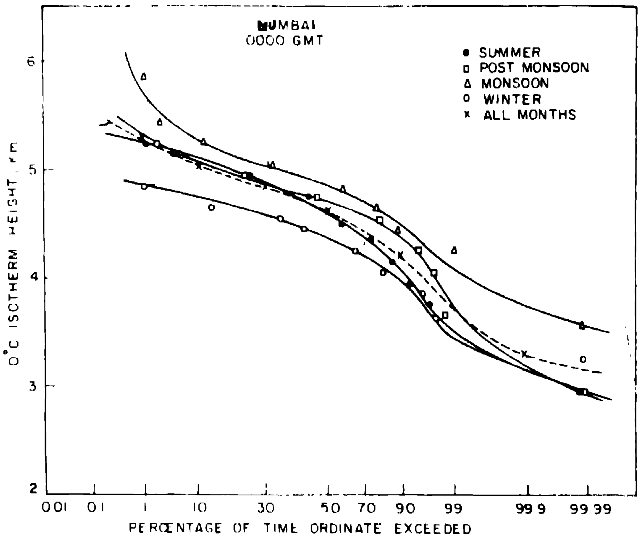

Figure 2. Probability distribution of 0°C isotherm height during different seasons over Mumbai

The results on 0°C isotherm height over Mumbai located in Indian west coast are shown in Figure 2. The 0°C isotherm height distributions during summer and monsoon months indicate that the 0°C isotherm height varies from ~2 98 km to 5 25 km during summer, while during monsoon 0°C isotherm height varies between ~3 55 km and 5 58 km The 0°C isotherm height is found to be minimum during winter months and maximum in monsoon The months of December, January and February constitute winter while March, April and May form the summer and June, July and August constitute monsoon seasons in Mumbai However, winter is mild in Mumbai as compared to the stations located in Indian northern plains The average temperature in Mumbai during December, January and February is ~22°C, 20°C and 21°C at 0000 GMT and ~28°C, 27°C and 28°C at 1200 GMT, respectively. The values of average relative humidity during December, January and February are 62%, 63% and 61% at 0000 GMT and it is 50%, 48% and 45% at 1200 GMT respectively. The summer months and winter months are associated with humidity around 60% to 70%. The average temperature in April and May is 28°C and 30°C at 0000 GMT and it is 30°C at 1200 GMT in both the months. It is already mentioned that the monsoon months are June, July and August in Mumbai. The total rainfall over Mumbai during these months are found to be ~647 mm, 945 mm and 660 mm and an appreciable rainfall (309 mm) takes place in September also The seasonal variation of 0°C isotherm height suggests that the 0°C isotherm height is dependent on local meteorological conditions.

The probability distribution of 0°C isotherm height for different periods including summer, monsoon, winter and all months over Guwahati are presented in Figure 3. It is seen from Figure 3 that the 0°C isotherm height during all months varies from ~2.50 km to 5.30 km between the probability levels 1.5% and 99.99%. The 0°C isotherm height is around ~4.30 km at 50% probability level over Guwahati. The 0°C isotherm height is found to be minimum during winter periods, while it is found to be maximum during monsoon months. The 0°C isotherm height is found to vary between ~2.90 km and 5.10 km from 1% to 99.99% probability levels during premonsoon months. It is thus seen that the variation of rain height over Guwahati during summer months is appreciable. The results on 0°C isotherm height reported here are useful to estimate the total attenuation over earth space path in the frequencies varying from 10 GHz to 400 GHz.

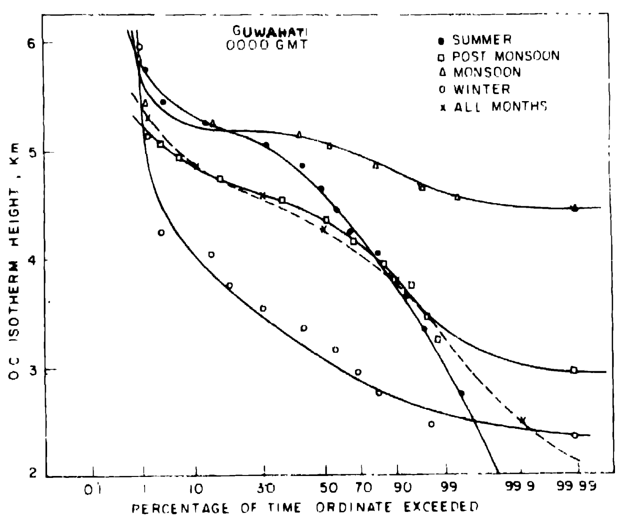

Figure 3. Probability distribution of 0°C isotherm height during different seasons over Guwahati

The summer, winter and monsoon are well defined over Guwahati. The peak summer months over Guwahati are April and May. The average temperature is ~26°C and 27°C at 0000 GMT is April and May respectively, while it is ~29°C at 1200 GMT in both the months April and May. The winter is normal in Guwahati. The average temperature in December, January and February during early morning is ~17°C, 16°C and 18°C. The monsoon over Guwahati is also normal. The total rainfall over Guwahati is 276 mm, 351 mm, 373 mm and 294 mm in May, June, July and August respectively.

The probability distributions of 0°C isotherm height observed during different seasons *e.g.* summer, monsoon and winter over Lucknow are presented in Figure 4. It is seen that the 0°C isotherm height varies from ~2.50 km to 5.25 km at 50% probability level. The 0°C isotherm height is maximum during monsoon and minimum in winter. It is also seen that the variation of 0°C isotherm height is not appreciable during monsoon months while the variations are significant during premonsoon and winter months.

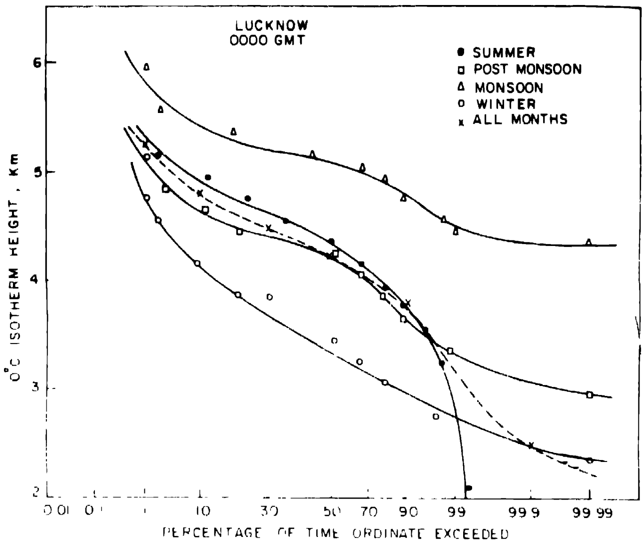

Figure 4. Probability distribution of 0°C isotherm height during different seasons over Lucknow.

The summer and winter are severe and monsoon is normal in Lucknow. The average temperature in April, May and June are ~28°C, 32°C and 32°C at 0000 GMT and 36°C, 39°C and 37°C at 1200 GMT respectively. The winter is severe in Lucknow. The average temperatures are 12°C, 12°C and 15°C at 0000 GMT and 19°C, 19°C and 24°C at 1200 GMT in December, January and February respectively. The total rainfall in monsoon months (July and August) are ~338 mm and 329 mm.

3. Determination of specific and total attenuation by CCIR method

The assumptions of microstructure of rainfall such as size distribution, temperature terminal velocity and shapes of rain drops are very important for the estimation of specific attenuation at a particular frequency for different rain rates. This is because, specific attenuation strongly depends on these parameters. The relation between the specific attenuation (α) and rain rate (R) for practical purposes is given by the following well known power law [5]

$$\alpha(R) = aR^b ,$$

where a and b are the constants depending on the frequency.

Assuming that the drops are spherical, the values of a, b were calculated by Olsen *et al* [5] at a number of frequencies between 1 GHz and 1000 GHz for several drop temperature and drop size distribution. The values of a and b have been estimated by assuming the rain drops to be oblate spheroidal aligned with a vertical rotation axis with dimensions related to equal volume spherical drops [6]. The values of a and b for horizontal and vertical polarisations given by Nowland *et al* [7] are presented in Table 2. Now for

Table 2. Values of a_H, a_V, b_H and b_V

Frequency GHz	a_H	a_V	b_H	b_V
1	0000387	00000352	912	880
2	000154	000138	963	923
4	000650	000591	1 121	1 075
6	00175	00155	1 308	1 265
7	00301	00265	1 332	1 312
8	00454	00395	1 327	1 310
10	0101	00887	1 276	1 264
15	0367	0335	1 154	1 128
20	0751	0691	1 099	1 065
25	124	113	1 061	1 030
30	187	167	1 021	1 000
35	263	233	979	963
40	350	310	939	929
45	442	393	903	897
50	536	479	873	868
60	707	642	826	824
70	851	784	.793	793
80	975	906	769	769
90	1 06	999	753	754
100	1 12	1 06	743	744
120	1 18	1 13	731	732
150	1 31	1 27	710	711
200	1 45	1 42	689	690
300	1.36	1 35	688	689
400	1 32	1.31	683	684

different measured rain rate, the specific attenuations are calculated at various frequencies ranging between 1 GHz and 400 GHz. The non-uniformity of rainfall in horizontal and vertical directions makes the evaluation of attenuation along earth space path complex. The model for the slant path suggests that the rain rate (R) exceeded for P% of time at ground level occurs for the same percentage of time upto the height (h_R), called the rain height [8,9]. It is also assumed that the attenuation due to rain does not occur above h_R.

The CCIR method of calculation of total attenuation along the slant path is given by CCIR [8,9]

$$A_R = \alpha(R)L_e,$$

where A_R is the attenuation exceeded for $P\%$ of time, α the specific attenuation and L_e the effective path length given by

$$L_e = r_p L_s,$$

where, r_p is the reduction factor and is given by

$$r_p = \frac{90}{90 + C_p L_G}$$

and

$$L_s = (H_t - H_0)/\sin\theta.$$

Here, H_t is the 0°C isotherm height and H_0 is the station height above mean sea level which has been taken as 0 for the present study. The values of C_p as given in the CCIR [8], are 9, 4, 0.5 and 0 respectively for rains occurring for 0.001%, 0.01%, 0.1% and 1% of time. The parameter L_G is the horizontal projection of the slant path.

Distribution of specific attenuation :

The specific attenuation at different frequencies for different rain rates is estimated The specific attenuation at 30 GHz, 100 GHz, 150 GHz, 200 GHz and 350 GHz are 17, 27

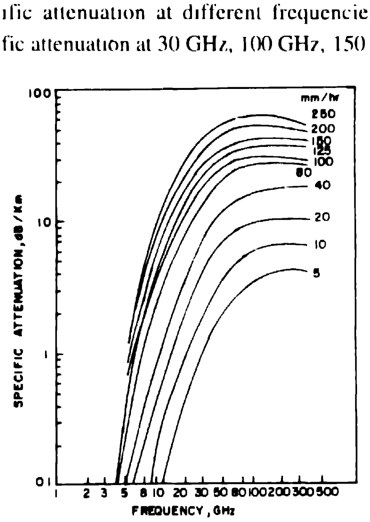

Figure 5. Variation of specific attenuation for different rain rates at different frequencies

31, 30 and 28 dB/km respectively for a rain rate of 100 mm/h. It means that as the frequency increases the specific attenuation also increases. The aforesaid freqnencies lie in the window regions. The ranges of windows are 24–48 GHz, 70–100 GHz, 120–166 GHz, 190–300 GHz and 350–400 GHz. It is seen from Figure 5 that the specific attenuation increases with increase of rain rate and follows almost a flat curve beyond 100 GHz for each of the individual rain rates. This is due to the fact that the rain drops which are responsible for large attenuation, fail to follow the alternations of the electric field which are very fast at higher frequencies.

4. Estimation of rain attenuation by using 0°C isotherm height and rain rate measurements

The rain imposes serious limitations on the performance of communication link and radar propagation in microwave and millimeter wave frequency bands. The effects increase as the frequency increases.

The results on attenuation of the radiowave due to rain at five frequencies in the range ~10 GHz to 400 GHz over Calcutta for earth space paths have been estimated. The results on attenuation at five frequencies have been obtained from rain rate measurements and rain heights. The rain rate measurements are taken by a rapid response rain gauge and rain height is estimated in relation to 0°C isotherm height. The data on rain rate pertain to the period 1988–91.

The distribution of rain rates observed at 0.1%, 0.01% and 0.001% during all months are ~80 mm/hr, 120 mm/hr and 185 mm/hr.

Here, 0.1% probability level suggests that for 0.1% of the time, including non-rainy period, rain rate 80 mm/h is exceeded in a year. Similarly, 0.01% probability level indicates that for 0.01% of the time, rain rate exceeds for 120 mm/h and 0.001% of time suggests that for 0.001% of time rain rate 185 mm/h is exceeded in a year including non rainy period.

The probability levels also suggest that for 0.001% of time *i.e.*, rain fall with high intensity occurs for short period in a year. Similarly, 0.1% indicates that rainfall with moderate intensity occurs for more time in a year.

Based on the observed rain rates and rain height in relation to 0°C isotherm heights, the results on attenuation of radiowave due to rain for 0.1%, 0.01% and 0.001% of the time over Calcutta have been derived by using the CCIR [6,8] method. The attenuation values over Calcutta for 80 mm/hr which exceeds for 0.1% of time is found to be ~80 dB at 30 GHz. It is seen that the measured rain rate ~120 mm/hr exceeds for 0.01% of time over Calcutta and the attenuation value at 0.01% of time is ~100 dB. The result on attenuation for rain rate ~185 mm/hr over Calcutta has also been obtained. Such rain rate exceeds for 0.001% of time. The attenuation value at ~30 GHz is found to be ~132 dB.

The results on attenuation at 80 GHz, 140 GHz, 250 GHz and 380 GHz have also been estimated for 0.1%, 0.01% and 0.001% probability levels. The details of the results on attenuation are presented in Table 3. It is seen that the attenuation value increases upto 140 GHz at all probability levels. The estimated values of attenuation at 140 GHz for 0.1%, 0.01% and 0.001% levels are 165 dB, 190 dB and 215 dB respectively while the attenuation values at 380 GHz are 110 dB, 160 dB and 180 dB for 0.1%, 0.01% and 0.001% probability respectively.

Table 3. Results on attenuation for earth-space path at different frequencies over Calcutta

Frequency		Attenuation		
	Probability levels Rain rate	0.1% 80 mm/h	0.01% 120 mm/h	0.001% 185 mm/h
30 GHz		80 dB	100 dB	132 dB
80 GHz		160 dB	180 dB	210 dB
140 GHz		165 dB	190 dB	215 dB
250 GHz		150 dB	170 dB	200 dB
380 GHz		110 dB	160 dB	180 dB

5. Conclusion

The results on 0°C isotherm height which is a measure of rain height reported in this paper over different stations in India can be utilized for estimation of attenuation of radiowave due to rain over earth space paths. The distribution of 0°C isotherm height over different stations and seasons indicates that 0°C isotherm height strongly depends on latitudes and local weather characteristics. Such investigations for more number of Indian locations/ stations under varied meteorological conditions should therefore be undertaken.

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